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13. ABSTRACT *(Maximum 200 words)*

The Static Coefficient of Friction (SCF) values were determined for several footwear soleing materials on different walkway surfaces, and for different surface conditions, to establish which soleing materials provided the best traction performance for shipboard application.

The soleing materials evaluated included a standard Navy safety boot with nitrile rubber sole, a Vibram nitrile commercial sole, the Army's prototype nitrile/neoprene multipurpose overboot (MULO) and vinyl overshoe, and three butyl chemical protective footwear covers. The walkway surfaces employed were stainless steel, aluminum, and new and worn non-skid coated steel. The SCF values were obtained with the surfaces dry, wet, and contaminated with oil. The ASTM "Standard Test Method for Static Coefficient of Friction of Shoe Sole and Heel Materials, as Measured by the James Machine", was used to determine the SCF values.

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The standard and MULO nitriles performed best when all walkway surfaces and conditions were considered. The excellent chemical resistance of the nitriles, and their high SCF values for a variety of surfaces and surface conditions evaluated in this study, makes them good candidate soleing materials for chemical agent protective footwear.

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INTRODUCTION

Based on a request from the Naval Sea Systems Command, Washington, DC, the Navy Clothing and Textile Research Facility (NCTRF) determined the Static Co-efficient of Friction (SCF) values for current and potential chemical agent protective footwear soleing materials on different walkway surfaces and for different surface conditions to establish which soleing materials provided the best traction performance for shipboard application. ASTM Standard F 489, "Standard Test Method for Static Co-efficient of Friction of Shoe Sole and Heel Materials as measured by the James Machine"[1] was used to determine the SCF values. A SCF value of 0.5 or greater was used to separate the performance of soleing materials having acceptable traction characteristics from those which did not[2].

The different soleing materials evaluated, represented those currently found in different Navy footwear items, the Army's multipurpose overboot and vinyl overshoe, and the United Kingdom's (UK) Ministry of Defense (MOD) chemical agent protective footwear covers. A commercial Vibram 134 soleing material was also evaluated. The Navy's work boot (MIL-B-21408 Boot, Safety) soleing material was used as the standard, since it represents the normal soleing material found in Navy work shoes and boots worn aboard ship. The composition of the soleing materials evaluated were butyl, vinyl, nitrile, and nitrile-neoprene. The nitrile-neoprene compound contained 75% nitrile and 25% neoprene. The walkway surfaces were stainless steel, aluminum, and new and worn non-skid coated steel and the SCF values were measured with the surfaces dry, wet (deionized water), and oily (10W oil).

The findings of this evaluation were as follows:

1. The Standard and MULO nitriles performed best when all walkway surfaces and surface conditions were considered. Their SCF values were greater than 0.5 for all surface and surface conditions.

2. The SCF values for the butyls, the Vibram nitrile, and the vinyl materials were acceptable for the dry and wet surface conditions (greater than 0.5 with all surfaces), but their SCF values for the oily condition were below or equal to 0.5 with the metal surfaces.

3. The SCF values for the butyls, compared to the other materials, were most affected with the metal surfaces for the oily surface condition. Their SCF values were 0.2 and less.

4. The SCF values for the nitriles on the aluminum surface were lower for the dry and wet conditions, compared to their SCF values on the stainless steel surface, and equivalent to their value for the oily condition on the stainless steel surface.

5. The SCF values for the vinyl were lower than the Standard and MULO nitriles for the metal surfaces for all surface conditions.

6. The SCF values for all soleing materials were equivalent or higher on the non-skid surfaces compared to their metal surface values for all surface conditions.

7. The SCF values for the materials and walkway surface interfaces evaluated in this study were most influenced by the nature of the contaminant. The oil contaminant with its greater lubricity compared to the water contaminant studied, produced lower SCF values for all materials and walkway surface interfaces evaluated, compared to their dry and wet condition values.

This report describes the soleing materials evaluated, the methods and procedures used, presents SCF results for the various conditions employed, discusses the influence of these conditions on the SCF data, and presents conclusions and recommendations.

BACKGROUND

On any given ship, a wide variety of walk and foot contact surfaces can be found. Flat surfaces include smooth painted steel decking, tile of various types (vinyl, quarry, clay, etc.), formed grating, and non-skid coated steel in various conditions of wear. The prime exterior shipboard surfaces (smooth and non-skid coated steel) can be contaminated with salt water, ice, oil, grease, hydraulic fluid, diesel fuel, jet fuel, or a combination of these contaminates. Non-flat surfaces, such as ladders, vary in design and differ in ngle of inclination, step width, and depth, step design and material, and handrail design.

A listing from the Navy Safety Center of 500 Navy lost time accidents, sorted by cause, showed that 177 (approximately 35%) were considered slip and fall accidents resulting from poor footwear soleing-walkway surface interfaces. Of these 177 accidents, 137 (77%) occurred aboard ship, with 49 (36%) associated with deck conditions, and the remaining 88 (64%) occurred with ladders. Of all shipboard accidents, 20%, 5%, and 3% involved a wet, icy, or oil contaminated surface respectively.

There is no current device or procedure that provides the means to determine the slip or traction characteristics of footwear soleing-walkway surface interfaces for the myriad of potential conditions (variables) that could be encountered aboard ship. As a result, the focus of this work was limited to determining the SCF values of soleing materials with flat walkway interface surfaces likely to be encountered aboard ship.

Of the current laboratory devices capable of measuring the SCF of footwear soleing materials, the Horizontal Pull Slipmeter, ASTM Method F 609[3] and the James Machine, ASTM Method F 489 were considered the most appropriate. Of these, the James Machine was selected for use in this study because it accommodated a larger sample (5.08 by 5.08 cm.) (3 x 3 in.) compared to three (3) 1.27 cm. (0.5 in.) diameter samples used with the Horizontal Pull Slipmeter. The larger sample made it possible to evaluate a complete tread pattern in all but one case, assuring that the physical interface of the footwear soleing material with the walkway surface was representative of that expected aboard ship.

DESCRIPTION OF MATERIALS

The characteristics of the soleing materials evaluated are shown in Table I. Four (4) different compositions (butyl, vinyl, nitrile, and nitrile/neoprene) with seven (7) different tread patterns (circular, conical, triangular, and rectangular geometries) are represented. The codes for the different tread patterns are also shown in Table I and photographs of the different tread patterns are depicted in Appendix A. The durometer hardness values for each material (Shore A Scale) are also indicated.

The indentation hardness of the footwear soleing materials, as represented by their durometer values, are dependent on the elastic modulus and visco-elastic behavior of the materials[4]. Lower durometer values represent softer materials.

SCF values can be affected by differences in chemical resistance of footwear soleing materials to an interface contaminant, such as oil. The chemical resistance of the soleing materials used in this study, to contaminates such as oils and solvents, is excellent for nitrile, good for neoprene, and fair for butyl[5]. No similar descriptive rating was found for the vinyl material because its chemical resistance is dependant on the plasticizers used to obtain a required flexibility[6].

The walkway surfaces were smoothed metal, stainless steel (SS), and aluminum (AL), and new and worn non-skid coated steel (NNS and WNS); these surfaces were similar to those found aboard ship. The non-skid coating was a mixture of grit particles and binder that created a surface having uniformly distributed nodules. The grit particles were located just below the surface of the binder for the NNS surface. The WNS surface was created by abrading the NNS coating with an aluminum oxide abradant until 42% of the coating was removed. The surface of the WNS compared to the NNS was flatter and some of the grit particles were directly exposed above the binder surface.

METHODS AND PROCEDURES

The SCF is equal to the ratio of the frictional force, parallel to the interface between the surface of two (2) materials (Fs), and a vertical force perpendicular to the frictional force, which maintains the two (2) surfaces in contact (N)[7].

$$SCF = Fs/N$$

The value of the SCF between two (2) material surfaces is related to the surface characteristics of the two (2) materials and their interface condition. Differences in the composition, configuration, and physical and chemical properties of the soleing materials; the non-presence or presence of a contaminant between the soleing and walkway surfaces and its surface characteristics; and differences in the surface characteristics of the walkway surfaces will all have some influence on the SCF value. The degree of influence that anyone of these features may have on the SCF values obtained, will be noted where discernible.

The presence of a surface contaminant at the interface of two (2) materials, creates two (2) surface interfaces instead of one. The top surface of the contaminant is in contact with the soleing material surface and the bottom surface of the contaminant is in contact with the walkway surface material. The use of an abrasive (grit) type walkway surface allows pressure on the soleing material to break-up the contaminant and force it into the voids between the peaks of the abrasive surface, retaining one interface between the soleing material and walkway surface material[8].

Seven (7) sole sample items with four (4) walkway surfaces and three (3) walkway surface conditions were evaluated in this study. ASTM Method F 489 was used in determining the SCF values for the soleing material-walkway surface interface conditions evaluated. The sole sample materials were taken from the ball area of the sole and encompassed at least one repeat of the tread pattern, except for the UK MK IV sole material, whose tread pattern repeat was larger than the sample size. The SS, AL, NNS, and WNS walkway surface materials were 30.4 cm. by 30.4 cm. (12 in. by 12 in.) in size.

The James Machine described in ASTM F 489 is shown in Figure 1. The sole sample was secured to a sample holder and the walkway surface material to the test table. Intimate contact between the sole sample and the walkway surface sample was achieved by applying an effective vertical force of 36.4 kg. (80 pounds) through a 25.4 cm. (10 in.) long circular strut to the horizontal sample holder. The other end of the strut was attached to a 36.4 kg. vertical weight assembly. At the start of each test, the strut was vertical to the sole sample and walkway surfaces (applied horizontal force = zero). The test table to which the walkway surface was attached was then moved relative to the sole sample material by an electric motor drive at a uniform rate of 2.54 cm./s. (1 in./s.). During this movement, the

weight assembly slowly drops vertically as the strut assumes a changing angular position, relative to the sole sample holder, imparting an increasing horizontal force to the sole sample material until there is a slippage between the sole sample material and the walkway surface (applied horizontal force = frictional force). The SCF value was determined from a calibrated chart that was attached to and moves with the test table. A pen attached to the weight assembly was in contact with the chart. The point where slippage occurs, causes a sudden vertical drop of the weight assembly. This movement is noted on the chart and indicates the SCF value.

Prior to testing, the SS, AL, NNS, and WNS walkway surface samples were cleaned with an ethyl alcohol-water solution, using a clean cloth. A plastic squeeze bottle was used to apply the contaminates to the walkway surfaces and a glass rod was then used to smooth the liquid over the walkway surface. Because of the surface tension between the deionized water contaminant and the SS and AL walkway surfaces, a beaded water surface was obtained. With the 10W oil contaminant, a continuous film surface was achieved for these surfaces. With the NNS and WNS walkway surfaces, a continuous film surface was obtained for both the water and the oil contaminants. The sole sample materials were prepared by sanding with a 60 grit silicon carbide abrasive paper to remove any finish on the material, smoothed by sanding with a 400A silicon carbide abrasive paper, and then brushed to remove any loose particles. The sole and walkway surface samples and contaminates were then conditioned at 75^{o}F. For the dry tests, the surfaces were conditioned for 18 hours.

Three (3) tests were normally conducted for each condition, each individual reading was recorded to two (2) decimal places, and the average value from the three (3) tests was reported to one decimal place, since duplicate determinations of the SCF values by different laboratories can vary by as much as 0.08 with this method[1]. In determining the suitability of a soleing material, the performance of each material was compared directly to the other materials, with respect to a specific walkway surface and surface condition employed, its overall performance for all surface and surface conditions, and its having a SCF value of 0.5 or more for all surface and surface conditions. The use of a SCF value of 0.5 as a minimum acceptable level was based on the findings of James[2]. In comparing field results obtained over several years with SCF laboratory results, using the James Machine, a SCF of 0.5 was found to be a safe value and its use was recommended to and adopted by the Casualty Council of Underwriters Laboratories for qualifying acceptable antislip materials.

RESULTS

SS Surface

Dry Condition - The SCF values for all soleing materials ranged from 0.7 to 1.0. The GVO vinyl had the lowest value (0.7), while the other soleing materials (butyls and nitriles) had SCF values ranging from 0.9 to 1.0 (Table II, Figure 2).

Wet Condition - The SCF values for all soleing materials ranged from 0.5 to 0.9. The GVO vinyl had the lowest value (0.5). The butyls, Modified MK III, MK IV, and MK III, had SCF values ranging from 0.6 to 0.9; and the nitriles, Standard, Vibram, and MULO, had SCF values ranging from 0.8 to 0.9 (Table II, Figure 2). Compared to their dry condition SCF values for the equivalent soleing material, the changes in SCF values were -10, -30, and -33 percent for the Modified MK III, MK IV, and MK III butyls respectively; -29 percent for the GVO vinyl; and -10, -10, and -11 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Oily Condition - The SCF values for all soleing materials ranged from 0.1 to 0.6. The three (3) butyls had the lowest SCF values, ranging from 0.1 to 0.2. The GVO vinyl and Vibram nitrile had an identical SCF value of 0.4. The Standard and MULO nitriles had the highest, with an identical SCF value of 0.6 (Table II, Figure 2). Compared to their dry condition SCF values for equivalent soleing materials, the changes in SCF values were -80, -90, and -89 percent for the Modified MK III, MK IV, and MK III butyls respectively, -43 percent for the GVO vinyl, and 40, -60, and -33 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Overall Performance - Considering all three (3) surface conditions, the Standard and MULO nitriles performed best, with the Standard showing slightly better performance. The Standard nitrile had SCF values for the dry and wet conditions of 1.0 and 0.9 respectively, compared to 0.9 and 0.8 for the MULO nitrile for these same conditions. The Standard and MULO nitriles had identical SCF values of 0.6 for the oily condition. The Vibram nitrile, vinyl, and butyls had SCF values below 0.5 for the oily condition, with the butyls having the lowest SCF values for this condition (0.1 to 0.2) (Table II, Figure 2).

AL Surface

Dry Condition - The SCF values for all soleing materials ranged from 0.7 to 1.1. The GVO vinyl had the lowest value (0.7) and the MULO nitrile had the next lowest value (0.8). The Modified MK III and MK IV butyls had the highest SCF values, 1.0 and 1.1 respectively. The MK III butyl and the remaining nitriles (Standard and Vibram) had an SCF value of 0.9 (Table III, Figure 3).

Wet Condition - The Modified MK III butyl and the Standard nitrile had the highest SCF value (0.8), the MK III butyl had the lowest SCF value (0.5), and the GVO vinyl had the next lowest value (0.6). The remaining butyl (MK IV) and nitriles (Vibram and MULO) had an identical SCF value of 0.7 (Table III, Figure 3). Compared to their dry condition, SCF values for the equivalent soleing material, the changes in SCF values were -20, -36, and -44 percent for the Modified MK III, MK IV, and MK III butyls respectively, -14 percent for the GVO vinyl, and -11, -22, and -13 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Oily Condition - The butyls had the lowest SCF values, ranging from 0.1 to 0.2. The Vibram nitrile and GVO vinyl had SCF values of 0.4 and 0.5 respectively. The highest SCF values were 0.6 and 0.7 for the Standard and MULO nitriles respectively (Table III, Figure 3). Compared to their dry condition SCF values for the equivalent soleing material, the changes in SCF values were -80, -91, and -89 percent for the Modified MK III, MK IV, and MK III butyls respectively, -29 percent for the GVO vinyl, and -33, -56, and -13 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Overall Performance - The Standard and MULO nitriles and the GVO vinyl had SCF values of 0.5 or higher for all three (3) surface conditions. Of these, the Standard nitrile had the highest SCF values for the dry and wet conditions, 0.9 and 0.8, respectively, while the MULO nitrile and GVO vinyl had SCF values of 0.8 and 0.7 and 0.7 and 0.6 respectively, for these same conditions. For the oily condition, the MULO nitrile had the highest SCF value, 0.7, and the Standard nitrile had the next highest value 0.6; the GVO vinyl just met the 0.5 minimum requirement for the oily condition. The performance of the Standard and MULO nitriles was essentially equivalent and superior to the GVO vinyl, considering all surface conditions. The butyls had very low and unacceptable SCF values (0.1 to 0.2) for the oily condition.

NNS Coated Steel Surface

Dry Condition - All of the materials had highly acceptable SCF values for this condition, ranging from 0.9 to 1.1. All of the butyls and the Vibram nitrile had a SCF value of 1.1, the Standard nitrile and GVO vinyl had an SCF value of 1.0, and the MULO nitrile had a SCF value of 0.9 (Table IV, Figure 4).

Wet Condition - All of the materials had highly acceptable SCF values for this condition also, ranging from 0.8 to 1.1. The Vibram nitrile had the highest SCF value (1.1), the butyls and the Standard nitrile had a SCF value of 1.0, and the MULO nitrile and GVO vinyl had SCF values of 0.9 and 0.8 respectively (Table IV, Figure 4). Compared to their dry condition SCF values for the equivalent soleing material, the changes in SCF values were -9 percent for the Modified MK III, MK IV, and MK III butyls, -20 percent for the GVO vinyl, and 0 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Oily Condition - All of the materials had acceptable SCF values for this condition, ranging from 0.6 to 1.1. The 1.1 SCF value for the GVO vinyl and Standard nitrile was higher than their SCF value of 1.0 for the dry condition. This does not seem plausible considering the contaminant was oil. The MULO nitrile had the highest credible SCF value (0.8), the Modified MK III and MK IV butyls, and the Vibram nitrile had a SCF value of 0.7, and the MK III butyl had the lowest value (0.6)

(Table IV, Figure 4). Compared to the SCF values for their dry condition values for the equivalent soleing material, the changes in SCF values were -36, -36, and -45 percent for the Modified MK III, MK IV, and MK III butyls respectively, +10 percent for the GVO vinyl, and +10, -36, and -11 percent for the Standard, Vibram, and MULO nitriles respectively. The positive percentages for the GVO vinyl and Standard nitrile are questionable, considering the contaminant was oil (Table VI).

Overall Performance - All of the materials had acceptable SCF values for all surface conditions. SCF values ranged from 0.9 to 1.1 for the dry condition, 0.8 to 1.1 for the wet condition, and the credible SCF values for the oily condition, ranged from 0.6 to 0.8. The best performing materials, not considering the GVO vinyl and Standard nitrile because their SCF seemed too high (higher than their dry condition value), was the Vibram nitrile, with an average SCF value for all three (3) surface conditions of 1.0. The average SCF value for the other remaining materials, butyls, and the MULO nitrile was slightly lower (0.9).

WNS Coated Steel Surface

Dry Condition - All of the materials had highly acceptable SCF values for this condition, ranging from 0.8 to 1.1. The MK III butyl material had the highest SCF value (1.1). The remaining butyls, Modified MK III and MK IV, GVO vinyl, and the Vibram nitrile had the next highest value (1.0), and the Standard and MULO nitriles had SCF values of 0.9 and 0.8 respectively (Table V, Figure 5).

Wet Condition - All of the materials had highly acceptable SCF values for this condition as well, ranging from 0.7 to 1.1. The MK III butyl had the highest SCF value (1.1). The Modified MK III butyl had a SCF value of 0.9 and the MK IV butyl, GVO vinyl, and the Standard and Vibram nitriles had a SCF value of 0.8; the MULO nitrile had an SCF value of 0.7 (Table V, Figure 5). Compared to their dry condition SCF values for the equivalent soleing material, the changes in SCF values were -10, -20, and 0 percent for the Modified MK III, MK IV, and MK III butyls respectively, -20 percent for the GVO vinyl, and -11, -20, and -13 percent for the Standard, Vibram, and MULO nitriles respectively (Table VI).

Oily Condition - All of the materials had acceptable SCF values for this condition, ranging from 0.5 to 1.1. The SCF values for the Standard and MULO nitriles, 1.1 and 0.9, and the GVO vinyl, 1.0, were higher and equal respectively, to their dry condition values, 0.9, 0.8, and 1.0 respectively. This did not seem plausible, considering the interface contaminant was oil. The Vibram nitrile had the highest credible SCF value (0.7), the butyls had the lowest SCF values for this condition, ranging from 0.5 to 0.6 (Table V, Figure 5). Compared to their SCF values for the

equivalent soleing material; changes in SCF values were -40, -40, and -55 percent for the Modified MK III, MK IV, and MK III butyls respectively, 0 percent for the GVO vinyl, and +22, -30, and +13 percent for the Standard, Vibram, and MULO nitriles respectively. The zero and the positive percentages for the GVO vinyl, and Standard and MULO nitriles are questionable, considering the surface contaminant was oil (Table VI).

Overall Performance - All of the materials had acceptable SCF values for all surface conditions. SCF values ranged from 0.8 to 1.1 for the dry condition, 0.7 to 1.1 for the wet condition, and the credible SCF values for the oily condition, ranged from 0.5 to 0.7. The best performing material, not considering the GVO vinyl, and Standard and MULO nitriles, because their SCF values seemed too high (equal or higher than their dry condition values) with an oil contaminant, was the MK III butyl; its average SCF value for all three surface conditions was 0.9. However, because of its marginal SCF value on the oily surface (0.5), it was rated lower than all the other materials. The average SCF value for the remaining materials, Vibram nitrile, and Modified MK III and MK IV butyls was 0.8.

DISCUSSION OF RESULTS

SS Versus AL Walkway Surfaces

Dry Condition - For the SS walkway surface, the butyl and nitrile type soleing materials had similar SCF values. The SCF values for both the butyl and nitrile items ranged from 0.9 to 1.0. The average SCF value was 1.0 and was identical for both the butyl and nitrile items. The GVO vinyl had the lowest SCF value, 0.7, compared to the butyl and nitrile items (Figure 6).

With the AL walkway surface, the average SCF value for the butyl items was identical to the value obtained with the SS surface (1.0). The range was 0.9 to 1.1 on the AL surface and 0.9 to 1.0 on the SS surface (Figures 6 and 7). The nitrile items had lower SCF values with the AL surface than with the SS surface. The average SCF value with the AL surface was 0.9, compared to 1.0 for the SS surface. The deviation in SCF values for the nitrile items was identical (0.1) with the AL and SS surfaces. The GVO vinyl had the lowest SCF value compared to the butyl and nitrile items on the SS and AL surfaces; its SCF value of 0.7 was identical on both surfaces (Figures 6 and 7).

Wet Condition - For the SS surface, the average SCF values were lower and had greater variability for the butyl items, compared to the nitrile items. The nitrile items had an average SCF value of 0.9, with a range of 0.8 to 0.9. The butyl materials had an average value of 0.7, with a range of 0.6 to 0.9. The GVO vinyl had a lower SCF value (0.5), than the butyl and nitrile items (Figure 6).

For the AL surface, the range of the SCF values was slightly lower than for the SCF values obtained on the SS surface for both the butyl and nitrile items. The average values were identical for the butyl items on both surfaces and lower for the nitrile items on the AL surface. The range for the butyl items on the SS surface was 0.6 to 0.9 and 0.5 to 0.8 on the AL surface. The range for the nitrile items was 0.8 to 0.9 and 0.7 to 0.8 on the SS and AL surfaces respectively. The average values were 0.7 and 0.9 for the butyl and nitrile items on the SS surface respectively, and 0.7 for the butyl and nitrile items on the AL surface. The SCF value for the GVO vinyl was lower (0.6) than the values for the nitrile items, but was higher than the SCF value for the MK III butyl item 0.6, compared to 0.5 (Figures 6 and 7).

The SCF value for the nitrile items were less influenced by the water contaminant than the butyl items. Compared to the butyl items, their average SCF value on the SS surface was higher, and equivalent on the AL surface. The variability of the SCF values of the nitrile items on the SS and AL surfaces was also lower, compared to the butyl items. The GVO vinyl was more influenced by the water contaminant, compared to the nitriles on the SS surface and equally affected, compared to the Standard and MULO nitriles on the AL surface (Table VI, Figures 6 and 7).

Reductions in SCF values compared to the dry condition ranged from 10 to 33 percent on the SS surface and 20 to 44 percent on the AL surface for the butyl items, 10 to 11 percent on the SS surface and 11 to 22 percent on the AL surface for the nitrile items, and 29 and 14 percent on the SS and AL surfaces respectively, for the GVO vinyl (Table VI).

Oily Condition - For the SS surface, the SCF values for the butyl items were substantially reduced. The average SCF value was 0.1 and the range was 0.1 to 0.2. The reductions in SCF values for the nitrile items with the SS surface were significantly less, with an average SCF value of 0.5 and a range of 0.4 to 0.6. The GVO vinyl had a SCF value of 0.4 which was higher than the butyls and equal to the Vibram nitrile (Figure 6).

For the AL surface, the results were essentially identical to those obtained on the SS surface. For the butyl items, the average SCF value was 0.1 and the range was 0.1 to 0.2. For the nitrile items, the average SCF value was 0.6 and the range was 0.4 to 0.7. The GVO vinyl had a SCF value of 0.5 which was higher than the butyls and the Vibram nitrile (Figure 7).

The nitrile items, based on their significantly higher SCF values on both the SS and AL surfaces, were less influenced by the oil contaminant than the butyl items. The MULO nitrile was also less influenced by the oil contaminant than the GVO vinyl. The GVO vinyl and the Standard nitrile were equally affected by the oil contaminant, and the GVO vinyl was less affected than the Vibram nitrile by the oil contaminant (Table VI, Figures 6 and 7).

Reductions in SCF values compared to the dry condition were 80 to 90 percent on the SS surface and 80 to 91 percent on the AL surface for the butyl items, 33 to 60 percent on the SS surface, and 13 to 56 percent on the AL surface for the nitrile items, and 43 and 29 percent on the SS and AL surfaces respectively for the GVO vinyl (Table VI).

Summary - Considering all three (3) surface conditions with the SS and AL surfaces, the Standard and MULO nitriles performed best. The butyl materials were eliminated because of their exceptionally low SCF values on the oily surfaces (0.1 to 0.2). The GVO vinyl material was also eliminated because it had generally lower SCF values than the nitriles except when compared to the Vibram nitrile for the oily AL surface condition. For this condition, the GVO vinyl had an SCF value of 0.5 and the Vibram nitrile had an SCF value of 0.4. The average SCF values for the Standard and MULO nitriles were 0.9 and 0.8 for the dry condition, 0.8 and 0.7 for the wet condition, and 0.6 for the oily condition respectively (Figures 6 and 7).

NNS Versus WNS Walkway Surfaces

Dry Condition - For the NNS surface, all of the butyl items had an identical SCF value of 1.1. The nitrile items had an average SCF value of 1.0 and a range of 0.9 to 1.1 on the NNS surface. The GVO vinyl had a SCF value of 1.0 on the NNS surface (Figure 8).

For the WNS surface, the butyl items had slightly lower SCF values than the NNS surface (average 1.0 and a range of 1.0 to 1.1). The nitrile items also had lower SCF values on the WNS surface (average 0.9 and a range of 0.8 to 1.0). The SCF value for the GVO vinyl was identical (1.0) on both the NNS and WNS surfaces (Figures 8 and 9).

Wet Condition - For the NNS surface, the SCF value was identical for all the butyl items (1.0). The SCF values for the nitriles were identical to those obtained for their dry condition (average 1.0 and a range of 0.9 to 1.1), and of a similar level to the butyl items. The GVO vinyl had an SCF value of 0.8 for the NNS surface, which was lower than the butyl and nitrile values obtained on the NNS surface (Figure 8).

For the WNS surface, the average SCF value for the butyl items was lower than for the NNS surface, and the individual values were more variable (average 0.9 and a range of 0.8 to 1.1). The SCF values for the nitrile items were lower on the WNS surface (average 0.8 and a range of 0.7 to 0.8), compared to an average of 1.0 and a range of 0.9 to 1.1 on the NNS surface. The GVO vinyl had an SCF value that was identical to its value on the NNS surface and the values for the MK IV butyl and Standard and Vibram nitriles on the WNS surface, 0.8 (Figures 8 and 9).

Reductions in SCF value compared to the dry condition for the butyl items was 9 percent, 0 percent for the nitriles, and 20 percent for the GVO vinyl with the NNS surface. For the WNS surface, the reductions in SCF values ranged from 0 to 20 percent for the butyls, 11 to 20 percent for the nitriles, and 20 percent for the GVO vinyl. The influence of the water contaminate was greatest for the GVO vinyl, least for the nitriles on the NNS surface, and similar for all materials on the WNS surface (Table VI).

Oily Condition - For the NNS surface, there was a significant reduction in the SCF values for the butyl items. The average SCF value was 0.7, and the range was 0.6 to 0.7. For the nitrile items, the SCF value for the Standard (1.1), was not deemed plausible for an oily surface, being higher than the dry condition value. The remaining nitriles (Vibram and MULO), had SCF values equal to and slightly higher than the average 0.7 value for the butyls, 0.7 and 0.8 respectively. The GVO vinyl also had a questionable SCF value for an oily surface (1.1), which was higher than its dry condition value of 1.0 (Figure 8).

For the WNS surface, the SCF values for the butyls were slightly lower than the values obtained on the NNS surface (average 0.6 and a range of 0.5 to 0.6). As occurred on the NNS surface, the SCF value for the Standard nitrile was higher (1.1), than for the dry condition (0.9), and seemingly not credible for an oily surface, but curiously identical to the result obtained on the NNS surface of the Standard. The SCF value for the MULO nitrile was also higher than its dry condition value (0.9 compared to 0.8), and was not considered plausible for the oily surface. The SCF value for the Vibram nitrile was slightly higher (0.7), than the average value for the butyls of 0.6. The SCF value for the GVO vinyl (1.0), was also questionable considering it was equal to its dry condition value for an oil contaminated surface. Again, as with the Standard nitrile, the GVO vinyl performed similarly on the NNS surface (Figures 8 and 9).

Changes in SCF values compared to the dry condition were -36 to -45 percent on the NNS surface; -40 to -55 percent on the WNS surface for the butyl items, +10 to -36 percent on the NNS surface, and +22 to -30 percent on the WNS surface for the nitriles, and +10 percent on the NNS surface and 0 percent on the WNS surface for the GVO vinyl. As indicated previously, the positive changes were not considered plausible with an oil contaminated surface, the influence of the oil contaminant was greatest for the butyl items on both the NNS and WNS surfaces (Table VI).

Summary - Considering all three (3) surface conditions with the NNS and WNS surfaces, and excluding the questionable SCF values for the Standard nitrile and GVO vinyl on the NNS surface, and the Standard and MULO nitriles and GVO vinyl on the WNS surface for the oily condition, the butyls, and the Vibram nitrile performed best. The average SCF values for all surface conditions was 0.9 with the NNS surface for the butyls and 1.0 for the Vibram nitrile. For the WNS surface, the average SCF value for all surface conditions was 0.8 for the butyls and the Vibram nitrile (Figures 8 and 9).

Metal Versus Non-Skid Surfaces

Dry Condition - The butyls had an average SCF value of 1.0 for all four (4) surfaces. The average SCF values for the nitriles were similar for the metal and non-skid surfaces: 1.0 on the SS, 0.9 on the AL, 1.0 on the NNS, and 0.9 on the WNS, being slightly less than the value for the butyls for the AL and WNS surfaces. For the GVO vinyl, the SCF values were significantly different on the metal surfaces compared to the non-skid surfaces. The average SCF value was 0.7 on the SS and AL surfaces and 1.0 for the NNS and WNS surfaces (Figure 10).

Wet Condition - The butyls had significantly different average SCF values on the metal surfaces compared to the non-skid surfaces. The average SCF value was 0.7 for both SS and AL surfaces, and 1.0 and 0.9 for the NNS and WNS surfaces respectively. The average SCF values for the nitriles were somewhat variable on both the metal and non-skid surfaces. The average SCF values ranged from 0.9 to 0.7 on the SS and AL surfaces respectively, and 1.0 to 0.8 on the NNS and WNS surfaces respectively. For the vinyl, the SCF values were significantly different, 0.5 and 0.6 on the SS and AL surfaces respectively, compared to 0.8 for both the NNS and WNS non-skid surfaces (Figure 10).

Oily Condition - The SCF values for the different materials were all significantly less for the metal surfaces compared to the non-skid surfaces. The butyls had an average SCF value of 0.1 for both the SS and AL surfaces, and 0.7 and 0.6 for the NNS and WNS surfaces respectively. Excluding the Standard nitrile on the NNS surface, and the Standard and MULO nitriles on the WNS surface, the nitriles had average SCF values of 0.5 and 0.6 for the SS and AL surfaces, and 0.7 for the NNS and WNS surfaces (Tables 4 and 5, Figure 10). The SCF values for the vinyl were excluded for the NNS and WNS surfaces because of its questionable values for the oily condition, preventing a comparison between the metal and non-skid surfaces.

Summary - The average SCF values for the butyls and nitriles on the metal and non-skid surfaces were essentially equivalent for the dry condition, and the range of SCF values for the butyl and nitrile materials were similar for the wet condition on all surfaces. For the oily condition, the SCF values for the nitriles were significantly higher than the butyls on the metal surfaces (Figure 10) and potentially higher on the non-skid surfaces, based on the trend of the curves for the oily condition for all surfaces (Figures 6 to 9). The butyls and nitriles had higher or equivalent SCF values on the non-skid surfaces, compared to their metal surface values. The SCF values for the vinyl material were significantly higher on the non-skid surfaces compared to their values for the metal surface. On the metal surfaces, the SCF values for the vinyl were generally lower than the butyl and nitrile materials, except for the oily condition where the SCF values for the vinyl were superior to the butyls and in a similar range as the nitriles (Figure 10).

Influences on SCF Values

Dry Condition - The primary cause for the SCF values obtained, appears to be related to the inherent interface compatibility between the soleing and walkway surface materials. Slight influences related to tread pattern differences could be attributed to the variation in the SCF values for a specific soleing and walkway surface material combination; butyls for the metal surfaces and the WNS surface, and the nitriles for all four (4) surfaces. The lower SCF values for the nitriles on the AL surface compared to the SS surface and for the WNS surface compared to the NNS surface, appears to result from dissimilar soleing and walkway surface affinities rather than any other conceivable cause. Any impact on SCF values resulting from changes in durometer values would be part of any change associated with tread pattern influences. The vinyl material had a greater affinity for the non-skid surfaces compared to the metal surfaces, as indicated by the higher SCF values obtained on the non-skid surfaces (Figures 6 to 9).

Wet Condition - There were significant reductions in SCF values for the butyls on the metal surfaces with the water contaminant, compared to their dry condition values. The changes in the SCF values were smaller on the non-skid surfaces (Figures 6 to 9). The reductions in the SCF values for all surfaces appeared to be related to a change in the compatibility of the soleing and walkway surface because of the water contaminant, and the ability of the different tread pattern designs to minimize the thickness of the water film between the tread and walkway surface interface, thereby increasing the adhesion between the tread and walkway surfaces[9]. With a pressure of approximately 9 psi applied to the tread and walkway surfaces at the beginning of each test, some of the liquid at the interface was diverted into the cavities between the tread surfaces. The effectiveness of a particular tread pattern to divert the liquid

and create a thin film at the tread and walkway surface interface, minimized the reduction in the SCF value obtained. The smaller changes in SCF values with the non-skid walkway surfaces were related to their surface roughness and the added ability to divert additional liquid into the spaces between the nodules of the non-skid surfaces.

The reductions in SCF values for the nitriles compared to their dry condition values were less than the butyls on the metal and NNS surfaces and essentially equivalent on the WNS surface. The mechanism for these changes were similar to the butyls, but the nitrile materials and tread designs were apparently more effective in reducing the interface thickness of the liquid film, resulting in correspondingly greater adhesion forces between the tread and walkway surfaces (Figures 6 to 9).

The vinyl material experienced reductions in SCF values of 29, 14, 20, and 20 percent for the SS, AL, NNS, and WNS surfaces respectively (Table VI). As with the butyl and nitrile materials, the higher SCF value of the vinyl material on the AL surface (0.6), compared to the SS surface (0.5), indicates that the vinyl was more effective in reducing the influence of the water contaminant on the AL surface. The higher and identical SCF value on the non-skid surfaces (0.8), as suggested previously, was related to the roughness of the non-skid surfaces and the additional ability to shunt more water away from the tread and walkway surface interface to the spaces between the nodules on the non-skid surfaces (Figures 6 to 9).

Oily Condition - There were substantial reductions in the SCF values for the butyls compared to their dry condition values on the SS and AL surfaces. The greater lubricity of the oil contaminant compared to the water contaminant and the apparent deterioration of the butyl surface, as indicated by skid marks on the walkway surface after slippage occurred, would account for the additional reductions in SCF values (Figures 6 and 7). The greater lubricity of the oil contaminant created greater reductions in SCF values than the wet condition for all walkway surfaces for the butyl materials.

There were also significant reductions in the SCF values of the nitrile materials on the metal surfaces and the Vibram nitrile on the non-skid surfaces, resulting from the oil contaminant at the interface of the tread and walkway surfaces. The reductions in the SCF values for the nitriles were less compared to the butyls on the metal surfaces which was believed influenced in part by the higher oil resistance of the nitriles (no evidence of soleing material deterioration) compared to the butyls. On the non-skid surfaces, even though the SCF values for the Standard nitrile on the NNS and WNS surfaces and the MULO nitrile on the WNS surface did not appear credible (greater than the dry condition value), it would seem that the SCF values for these materials on these walkway surfaces would be greater than the butyls because the trend of the curves on the NNS and WNS surfaces were similar to what occurred on the metal surfaces (Figures 6 to 9).

The vinyl materials also had significant reductions in SCF values on the metal surfaces. On the non-skid surfaces, the changes in the SCF values were +10 and 0 percent on the NNS and WNS surfaces respectively (Table VI). These changes, as with the Standard and MULO nitriles, did not seem credible with an oil contaminant. The mechanism relating to changes in SCF values on the metal surfaces was as indicated previously (Figures 6 to 9).

Overall Summary

For the SS and AL surfaces for all three (3) surface conditions, the Standard and MULO nitriles performed best. The average SCF values for the Standard and MULO nitriles were 0.9 and 0.8 for the dry condition, 0.8 and 0.7 for the wet condition, and 0.6 for the oily condition. The butyl and vinyl items were eliminated because of their low SCF values with the oily condition.

With the NNS and WNS surfaces, and excluding the questionable SCF values for the Standard and MULO nitriles and the GVO vinyl for the oily condition, the butyls and the Vibram nitrile performed best. The average SCF values for the butyls and Vibram nitriles were 0.9 and 1.0 respectively, on the NNS surface, and 0.8 for the butyls and the Vibram nitrile on the WNS surface (Figures 8 and 9). Based on the trend of the curves in Figures 6 to 9 for the nitrile materials with the oily condition, the SCF values for the Standard and MULO nitriles should be greater than the Vibram nitrile. Considering their dry and wet condition values also, the Standard and MULO nitriles would perform well on the non-skid surfaces for all conditions.

For the metal and non-skid surfaces, the average SCF values for the butyls and the nitriles were essentially equivalent for the dry condition, and the range of SCF values for the butyl and nitrile materials were similar for the wet condition on all surfaces. For the oily condition, the SCF values for the nitriles were significantly higher than the butyls on the metal surfaces (Figure 10), and potentially higher on the non-skid surfaces based on the trend of the curves for the oily condition for all surfaces (Figures 6 to 9). The butyls and nitriles also had higher or equivalent SCF values on the non-skid surfaces, compared to their metal surface values. The SCF values for the vinyl material were significantly higher on the non-skid surfaces, compared to their values on the metal surfaces. On the metal surfaces, the SCF values for the vinyl were generally lower than the butyl and nitrile materials, except for the oily condition, where the SCF values for the vinyl were superior to the butyls and in a similar range as the nitriles (Figure 10).

CONCLUSIONS

1. The Standard and MULO nitriles performed best when all walkway surfaces and surface conditions were considered. Their SCF values were greater than 0.5 for all surface and surface conditions.

2. The SCF values for the butyls, the Vibram nitrile, and the vinyl materials were acceptable for the dry and wet surface conditions, greater than 0.5 with all surfaces, but their SCF values for the oily condition were below or equal to 0.5 with the metal surfaces.

3. The SCF values for the butyls, compared to the other materials, were most affected with the metal surfaces for the oily surface condition. Their SCF values were 0.2 and less.

4. The SCF values for the nitriles on the aluminum surface were lower for the dry and wet conditions, compared to their SCF values on the stainless steel surface, and equivalent to their value for the oily condition on the stainless steel surface.

5. The SCF values for the vinyl were lower than the Standard and MULO nitriles for the metal surfaces for all surface conditions.

6. The SCF values for all soleing materials were equivalent or higher on the non-skid surfaces, compared to their metal surface values for all surface conditions.

7. The SCF values for the materials and walkway surface interfaces evaluated in this study were most influenced by the nature of the contaminant. The oil contaminant, with its greater lubricity compared to the water contaminant studied, produced lower SCF values for all materials and walkway surface interfaces evaluated, compared to their dry and wet condition values.

RECOMMENDATIONS

1. For the general evaluation of SCF values of footwear soleing materials to be utilized aboard ship, the stainless steel and new non-skid coated steel walkway surfaces would be most representative of those found shipboard, and more likely to provide repeatable results using the James Machine. Variable results would be expected with worn non-skid steel surfaces, and with the aluminum surface, the formation of an oxide coating is possible during the 18 hour conditioning period described in ASTM Standard F 489, which could reduce the SCF values obtained for dry surface conditions.

2. Walkway surface cleaning methods and means of applying contaminants to the walkway surface should be explored to insure results are repeatable.

TABLE I. Description of Footwear Soleing Materials

Item	Description	Sole Material	Tread Pattern	Durometer Shore A
UK Mod. MK III	Footwear Cover, Fishtail design	Butyl	Concentric Cylinders (CC)	55
UK MK IV	Footwear Cover, Fishtail design, Heel Pocket	Butyl	Chevron/Bar (C/B)	60
UK MK III	Footwear Cover, Fishtail Design	Butyl	Circular Plugs (CP)	65
GVO	Overshoes, Combat, MIL-O-43995	Vinyl	Conical Plugs with Concave Tips (CP/CT)	60
Standard	Boot, Safety, MIL-B-21408 (Navy Work Boot)	Nitrile	Chevron (C)	70
Vibram 134	Commercial Soleing Material	Nitrile	Cylindrical Plugs & Rectangular Bars (CP/RB)	75
MULO	Overboot, Multipurpose	Nitrile/ Neoprene	Bias Rectangular Offset Blocks (BROB)	80

TABLE II. Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Stainless Steel Surfaces Using the James Machine

Item	Sole Material	Tread Pattern	Surface Condition Dry Avg	Wet Avg	Oil Avg
UK Mod. MK III	Butyl	Concentric Cylinders	1.0	.9	.2
UK MK IV	Butyl	Chevron/Bar	1.0	.7	.1
UK MK III	Butyl	Circular Plugs	.9	.6	.1
GVO	Vinyl	Conical Plugs with Concave Tips	.7	.5	.4
Standard	Nitrile	Chevron	1.0	.9	.6
Vibram 134	Nitrile	Cylindrical Plugs, Rectangular Bars	1.0	.9	.4
MULO	Nitrile/Neoprene	Bias Rectangular Offset Blocks	.9	.8	.6

TABLE III. Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Aluminum Surfaces Using the James Machine

Item	Sole Material	Tread Pattern	Surface Condition Dry Avg	Wet Avg	Oil Avg
UK Mod. MK III	Butyl	Concentric Cylinders	1.0	.8	.2
UK MK IV	Butyl	Chevron/Bar	1.1	.7	.1
UK MK III	Butyl	Circular Plugs	.9	.5	.1
GVO	Vinyl	Conical Plugs with Concave Tips	.7	.6	.5
Standard	Nitrile	Chevron	.9	.8	.6
Vibram 134	Nitrile	Cylindrical Plugs, Rectangular Bars	.9	.7	.4
MULO	Nitrile/Neoprene	Bias Rectangular Offset Blocks	.8	.7	.7

TABLE IV. Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily New Non-Skid Coated Steel Surfaces Using the James Machine

Item	Sole Material	Tread Pattern	Surface Condition: Dry Avg	Wet Avg	Oil Avg
UK Mod. MK III	Butyl	Concentric Cylinders	1.1	1.0	.7
UK MK IV	Butyl	Chevron/Bar	1.1	1.0	.7
UK MK III	Butyl	Circular Plugs	1.1	1.0	.6
GVO	Vinyl	Conical Plugs with Concave Tips	1.0	.8	1.1*
Standard	Nitrile	Chevron	1.0	1.0	1.1*
Vibram 134	Nitrile	Cylindrical Plugs, Rectangular Bars	1.1	1.1	.7
MULO	Nitrile/Neoprene	Bias Rectangular Offset Blocks	.9	.9	.8

* SCF value for GVO vinyl with oil contaminated surface greater than dry surface SCF.
SCF value for Standard nitrile with oil contaminated surface greater than dry surface SCF.

TABLE V. Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Worn Non-Skid Coated Steel Surfaces Using the James Machine

Item	Sole Material	Tread Pattern	Surface Condition: Dry Avg	Wet Avg	Oil Avg
UK Mod. MK III	Butyl	Concentric Cylinders	1.0	.9	.6
UK MK IV	Butyl	Chevron/Bar	1.0	.8	.6
UK MK III	Butyl	Circular Plugs	1.1	1.1	.5
GVO	Vinyl	Conical Plugs with Concave Tips	1.0	.8	1.0*
Standard	Nitrile	Chevron	.9	.8	1.1*
Vibram 134	Nitrile	Cylindrical Plugs, Rectangular Bars	1.0	.8	.7
MULO	Nitrile/Neoprene	Bias Rectangular Offset Blocks	.8	.7	.9*

* SCF value for GVO vinyl with oil contaminated surface equal to dry surface SCF.
SCF value for Standard nitrile with oil contaminated surface greater than dry surface SCF.
SCF value for MULO nitrile/neoprene with oil contaminated surface greater than dry surface SCF.

TABLE VI. Percentage Change in the Static Coefficient of Friction Values Compared to their Dry Condition Values for the Various Material-Surface Interface Conditions Evaluated

Material	Item	Surface Condition	Surface: SS	Surface: AL	Surface: NNS	Surface: WNS
Butyl	UK Mod. MK III	Wet	-10	-20	-9	-10
		Oil	-80	-80	-36	-40
	UK MK IV	Wet	-30	-36	-9	-20
		Oil	-90	-91	-36	-40
	UK MK III	Wet	-33	-44	-9	0
		Oil	-89	-89	-45	-55
Vinyl	GVO	Wet	-29	-14	-20	-20
		Oil	-43	-29	+10*	0*
Nitrile	Standard	Wet	-10	-11	0	-11
		Oil	-40	-33	+10*	+22*
	Vibram	Wet	-10	-22	0	-20
		Oil	-60	-56	-36	-30
Nitrile/ Neoprene	MULO	Wet	-11	-13	0	-13
		Oil	-33	-13	-11	+13*

* NNS SCF value for GVO vinyl with oil contaminated surface greater than dry surface SCF.
SCF value for Standard nitrile with oil contaminated surface greater than dry surface SCF.

* WNS SCF value for GVO vinyl with oil contaminated surface equal to dry surface SCF.
SCF value for Standard nitrile with oil contaminated surface greater than dry surface SCF.
SCF value for MULO nitrile/neoprene with oil contaminated surface greater than dry surface SCF.

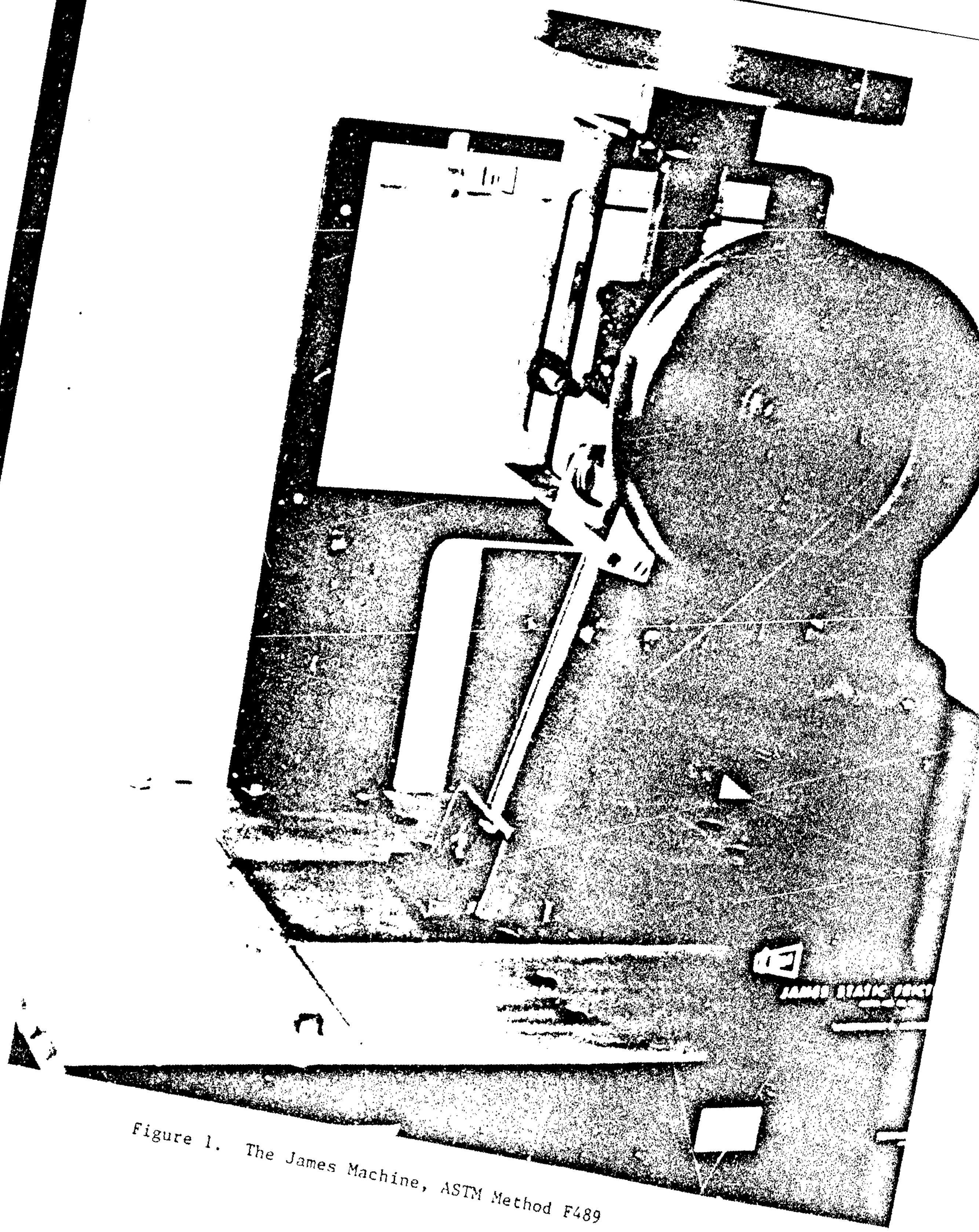

Figure 1. The James Machine, ASTM Method F489

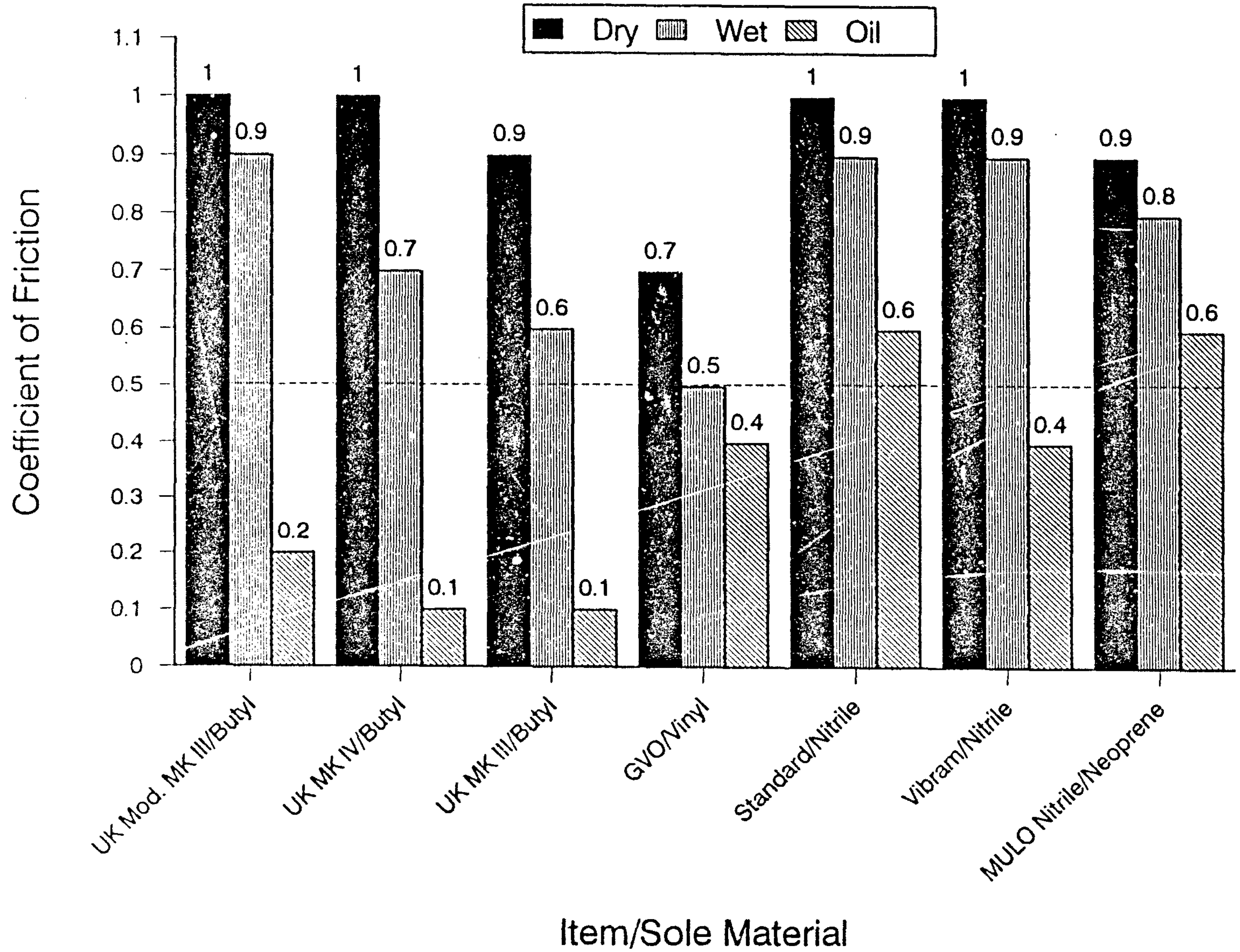

Figure 2 Static Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Stainless Steel Surfaces Using the James Machine

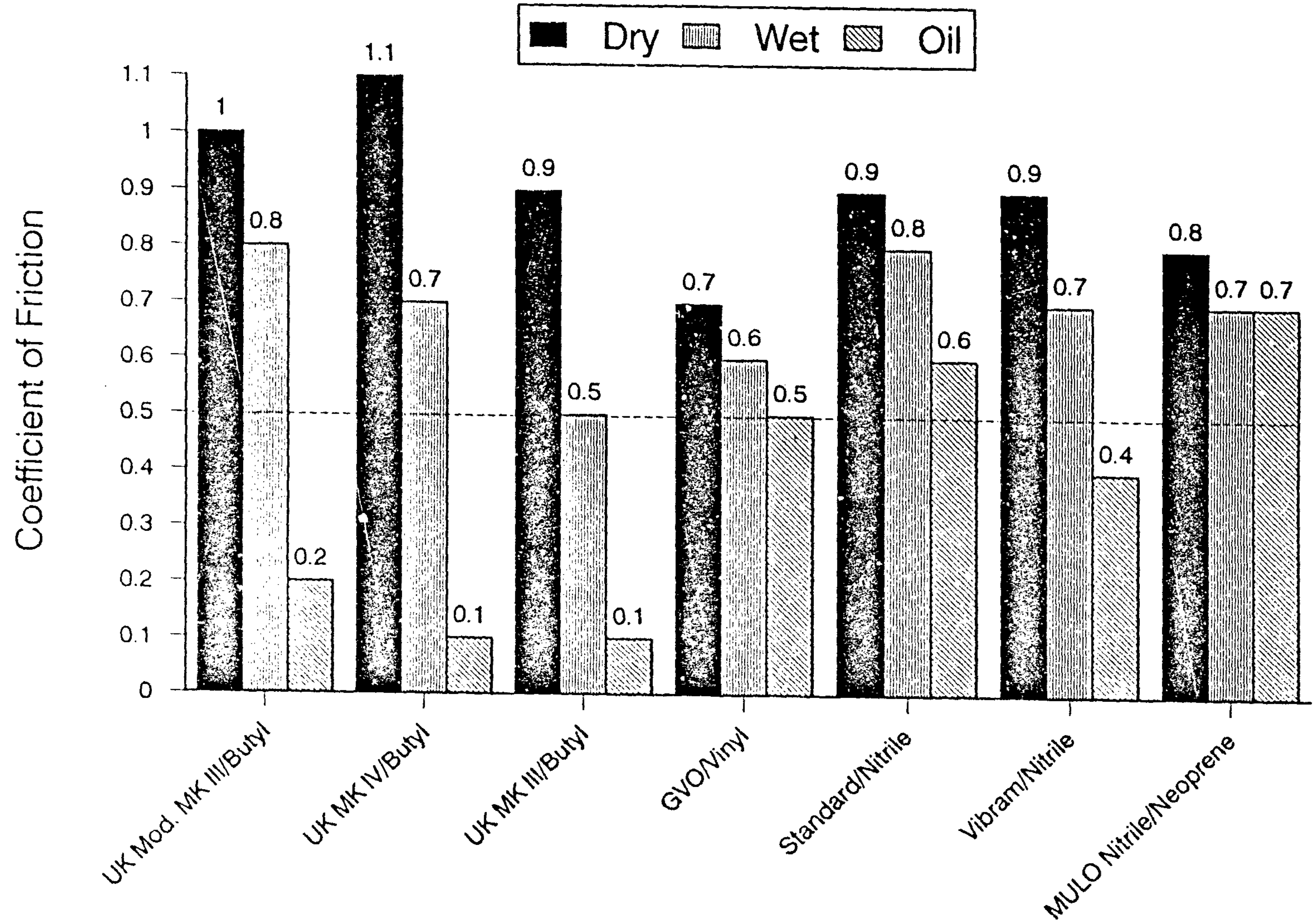

Figure 3 Static Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Aluminum Surfaces Using the James Machine

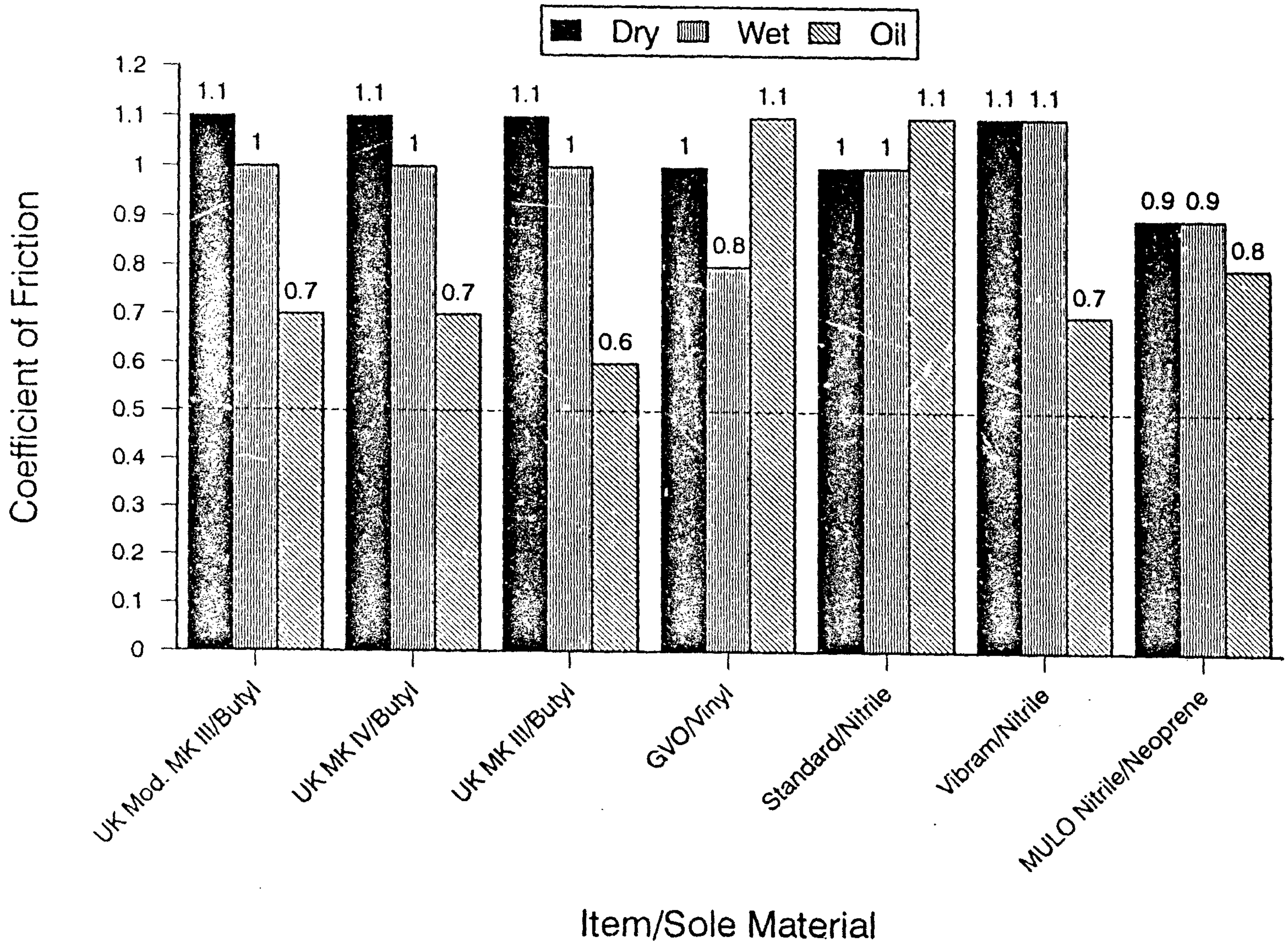

Figure 4 Static Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily New Non-Skid Coated Steel Surfaces Using the James Machine

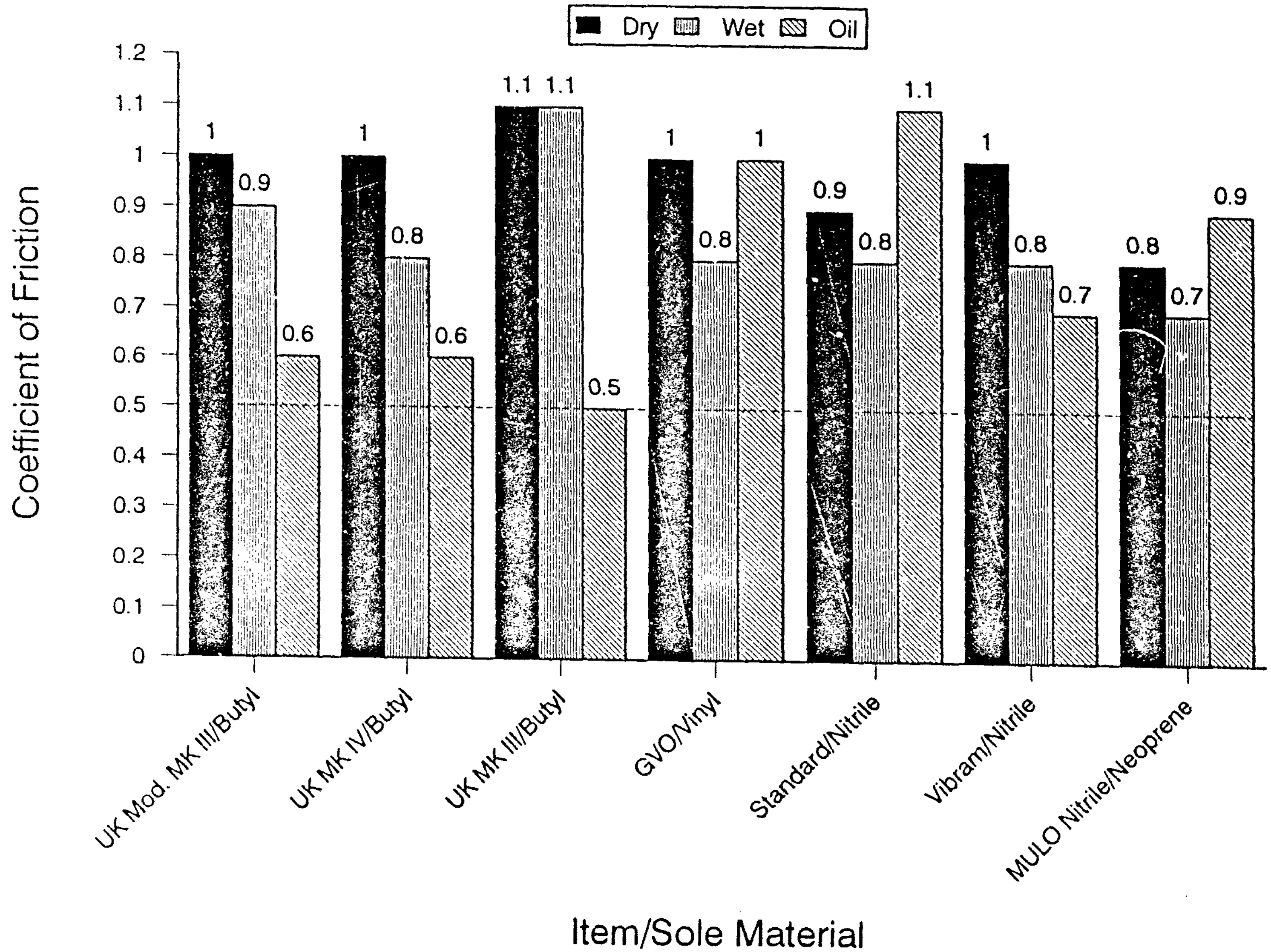

Figure 5 Static Coefficient of Friction Values of Footwear Soleing Materials with Dry, Wet, and Oily Worn Non-Skid Coated Steel Surfaces Using the James Machine

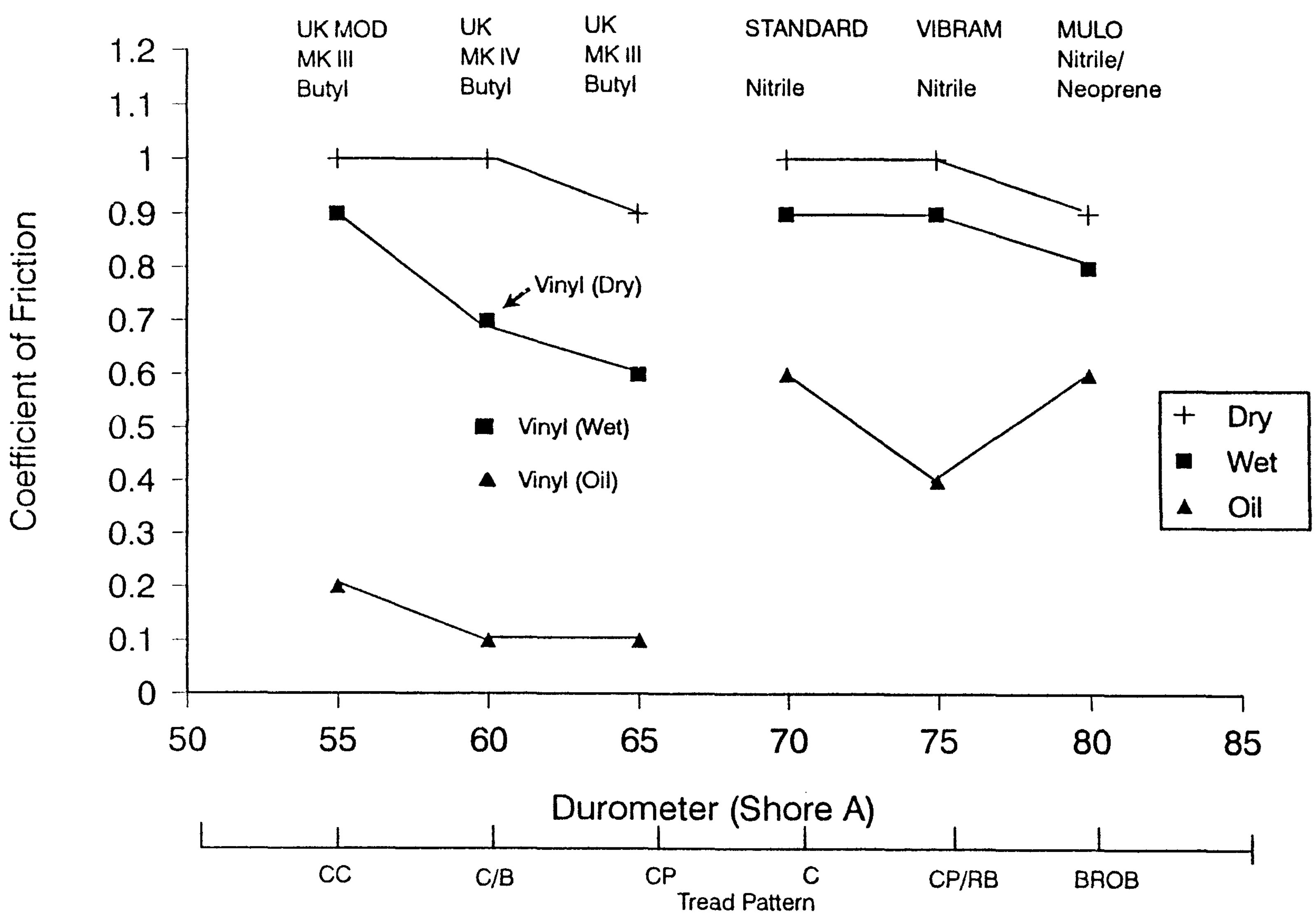

Figure 6 Effect of Differences in Soleing Material Compositon, Durometer Hardness Values, and Tread Pattern Geometries Compared to Contaminated Stainless Steel Surfaces on Changes in Coefficient of Function Values

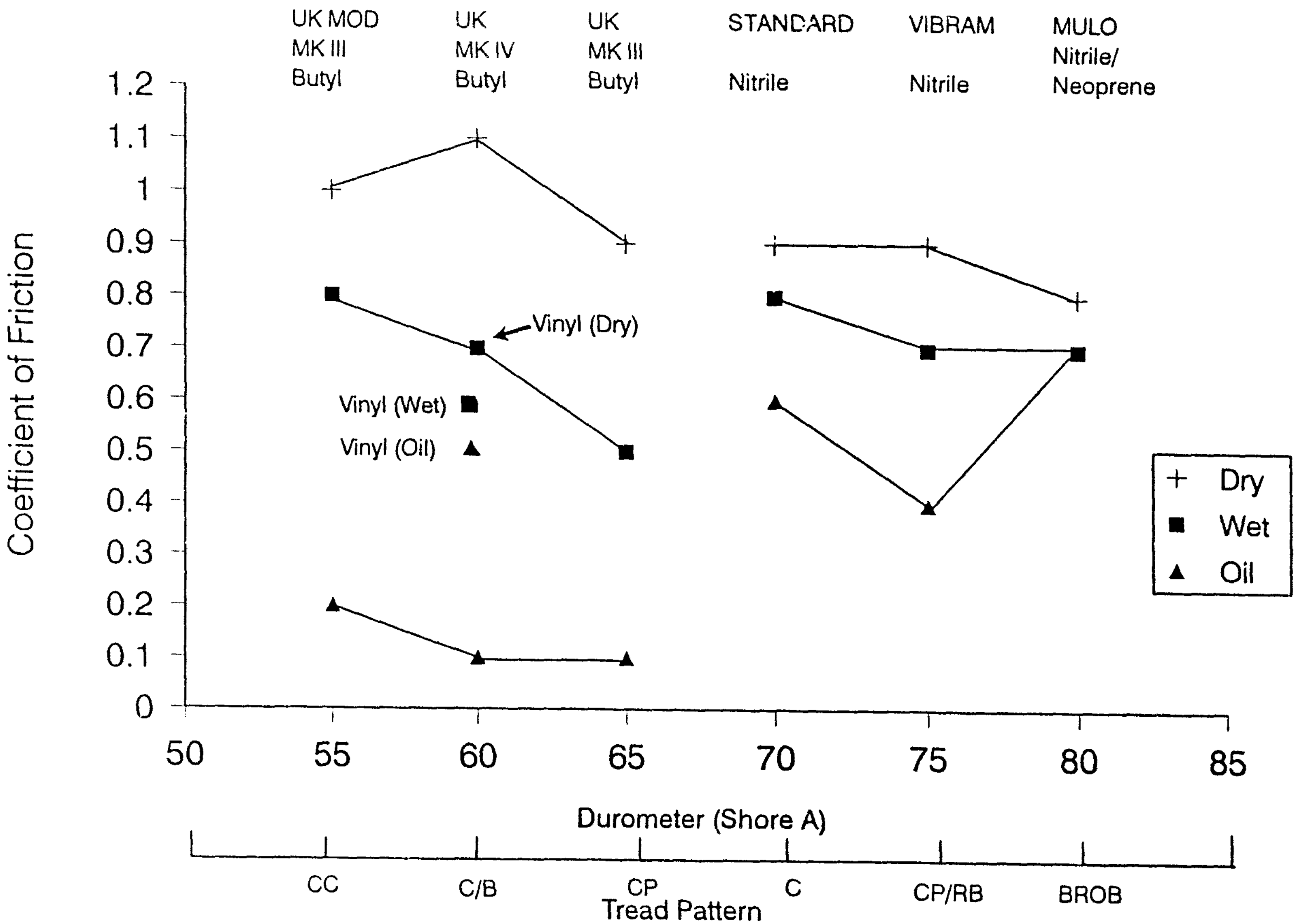

Figure 7 Effect of Differences in Soleing Material Composition, Durometer Hardness, and Trend Pattern Geometries Compared to Contaminated Aluminum Surfaces on Changes in Coefficient of Friction Values

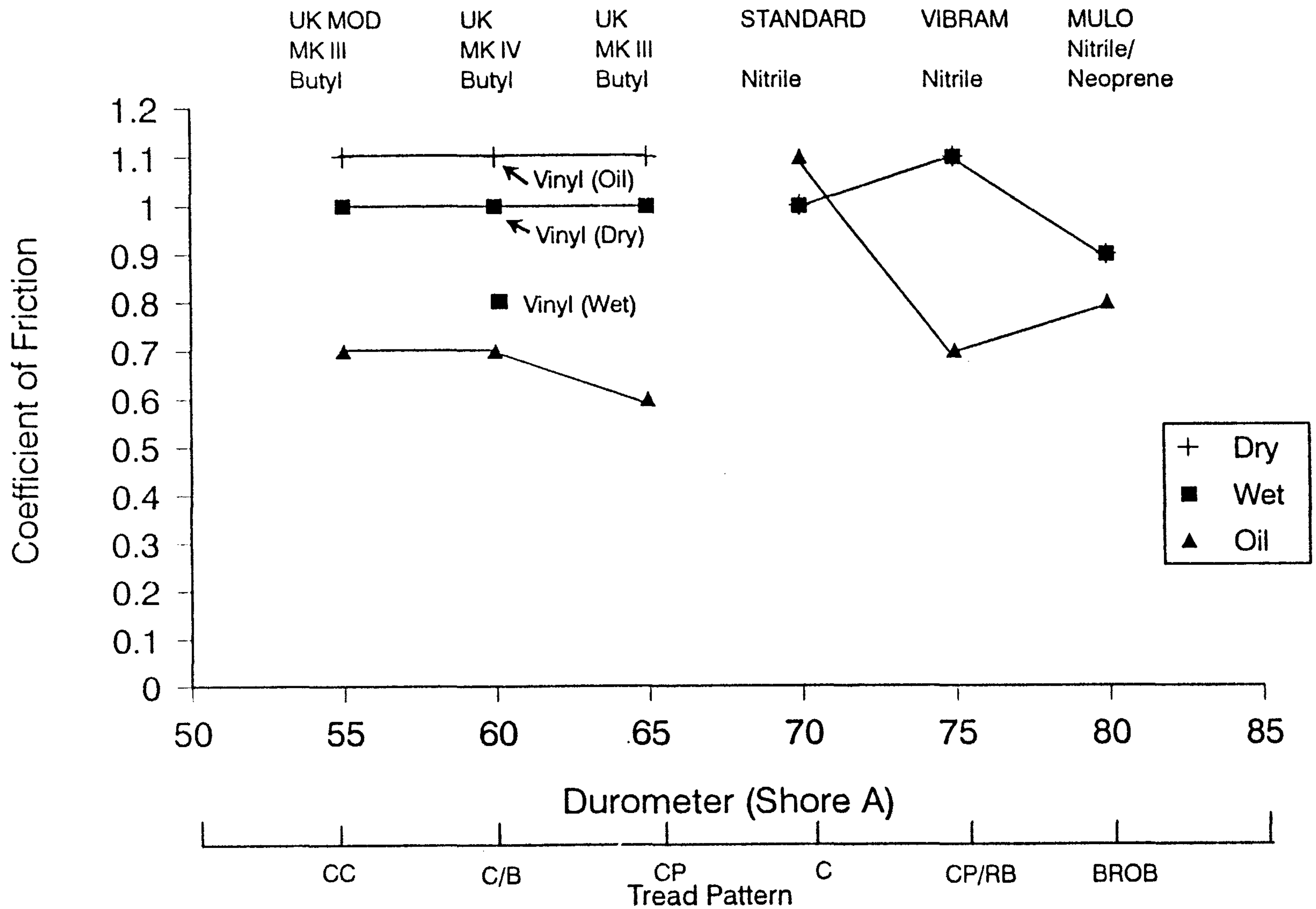

Figure 8 Effect of Differences in Soleing Material Composition, Durometer Hardness Values, and Tread Pattern Geometries Compared to Contaminated New Non-Skid Coated Steel Surfaces on Cahnges in Coefficient of Function Values

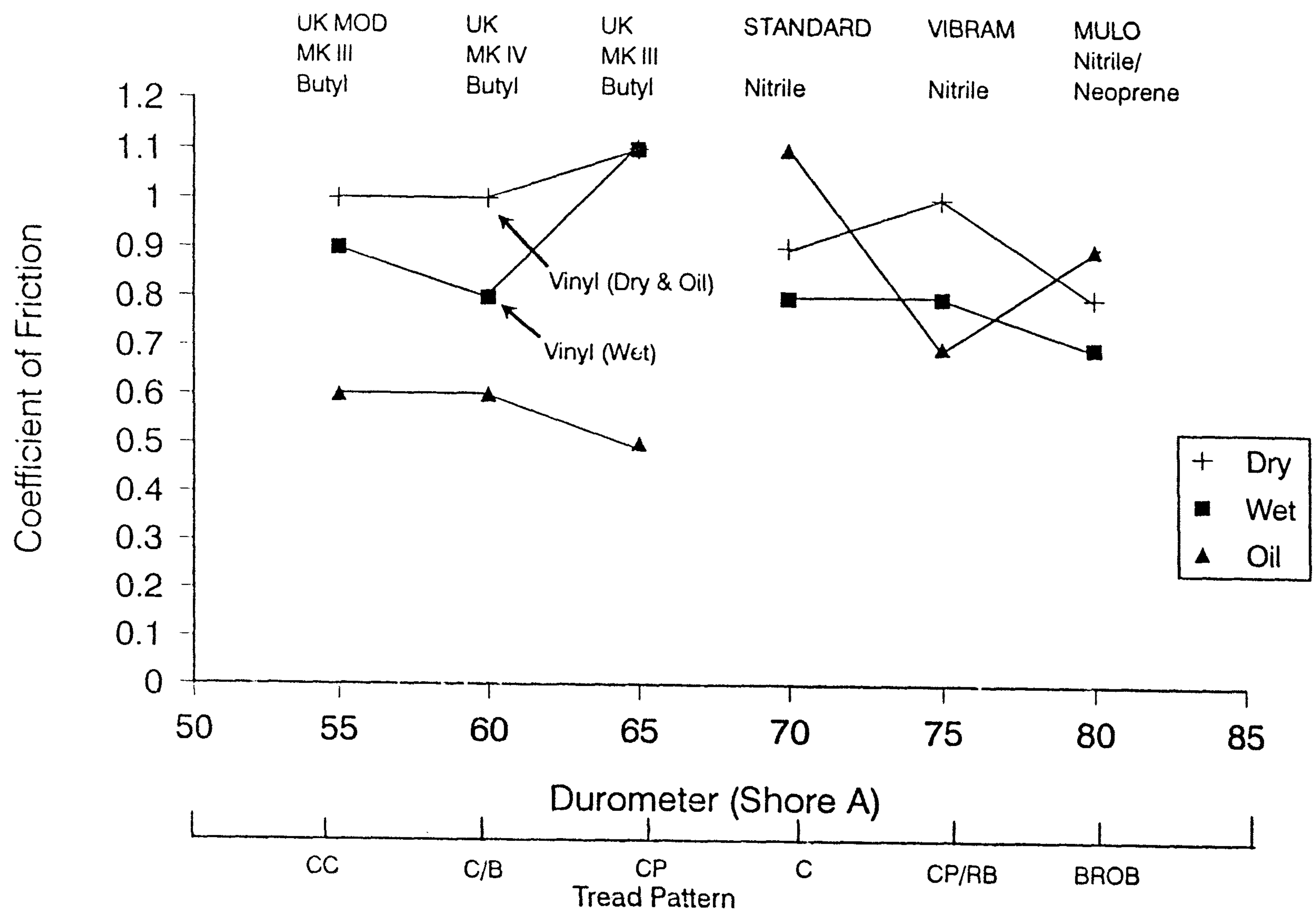

Figure 9 Effect of Differences in Soleing Material Composition, Durometer Hardness Values, and Tread Pattern Geometries Compared to Contaminated Worn Non-Skid Coated Steel Surfaces on Changes in Coefficient of Function Values

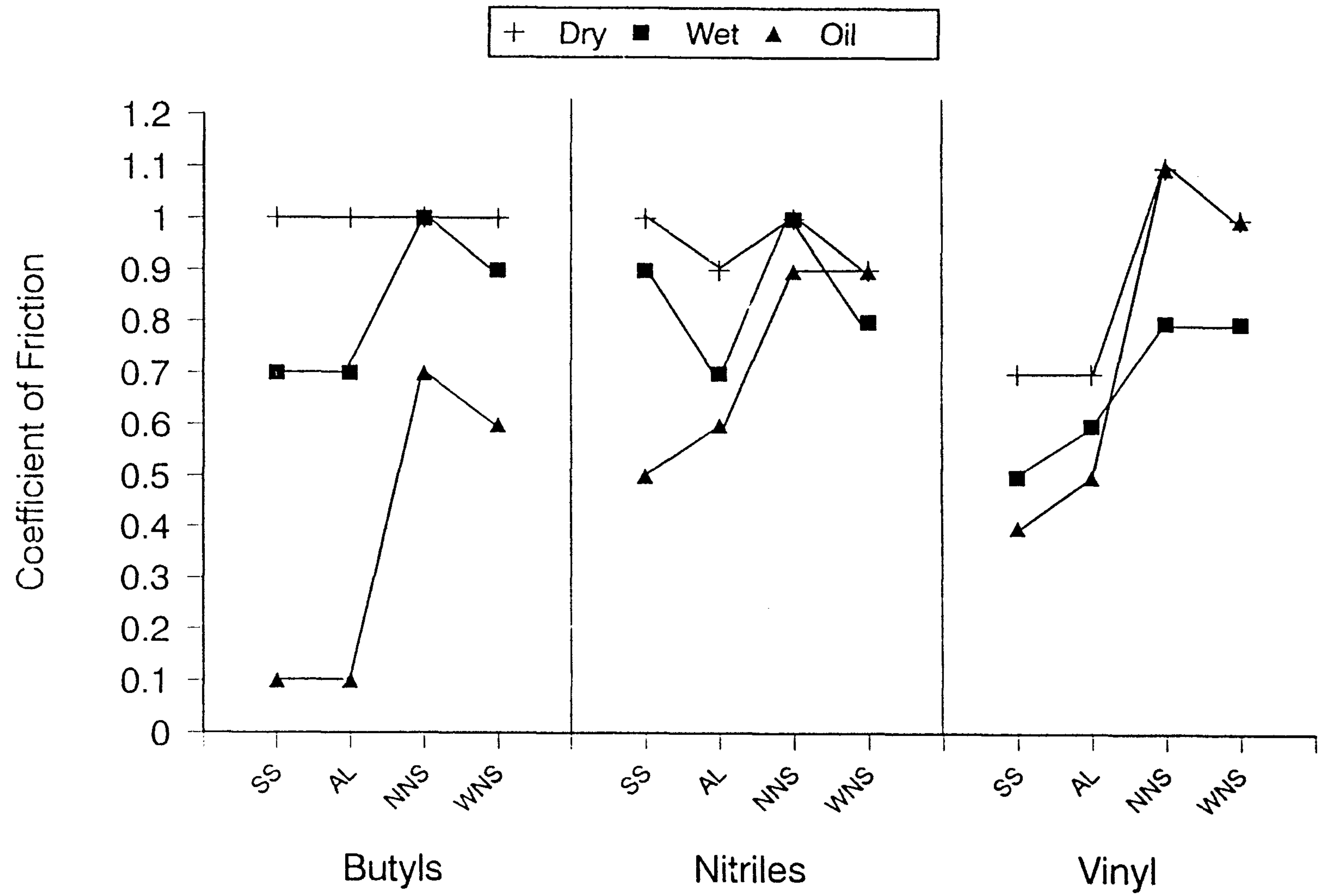

Figure 10 Comparison of Average Static Coefficient of Friction Values of Footwear Soleing Material with Dry, Wet, and Oily Metal and Non-Skid Walkway Surfaces

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APPENDIX A

Tread Patterns for Footwear Soleing Materials

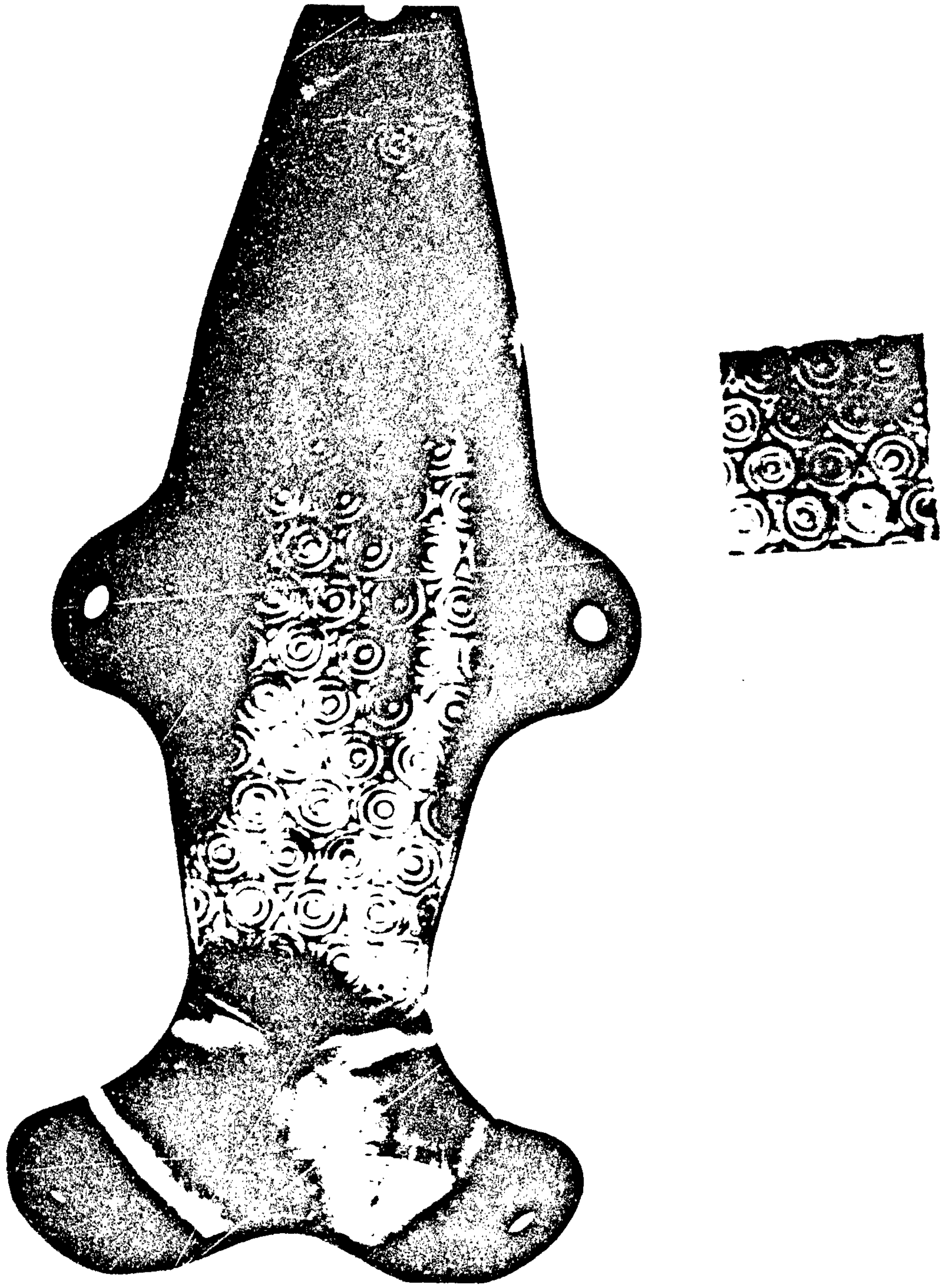

Figure A-1. UK Modified MKIII Butyl Soleing Material
- Concentric Cylinder Tread Pattern

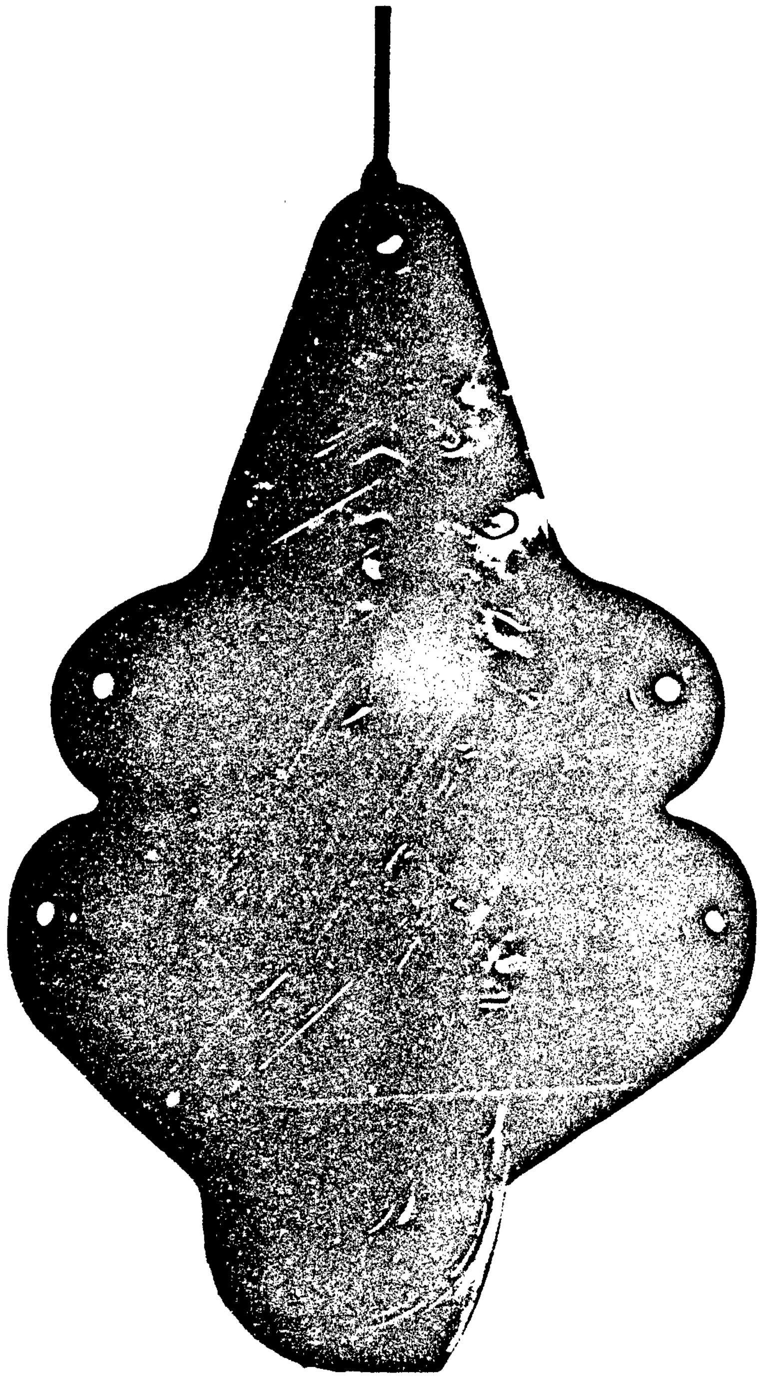

Figure A-2. MK IV Butyl Soleing Material - Chevron/Bar Tread Pattern

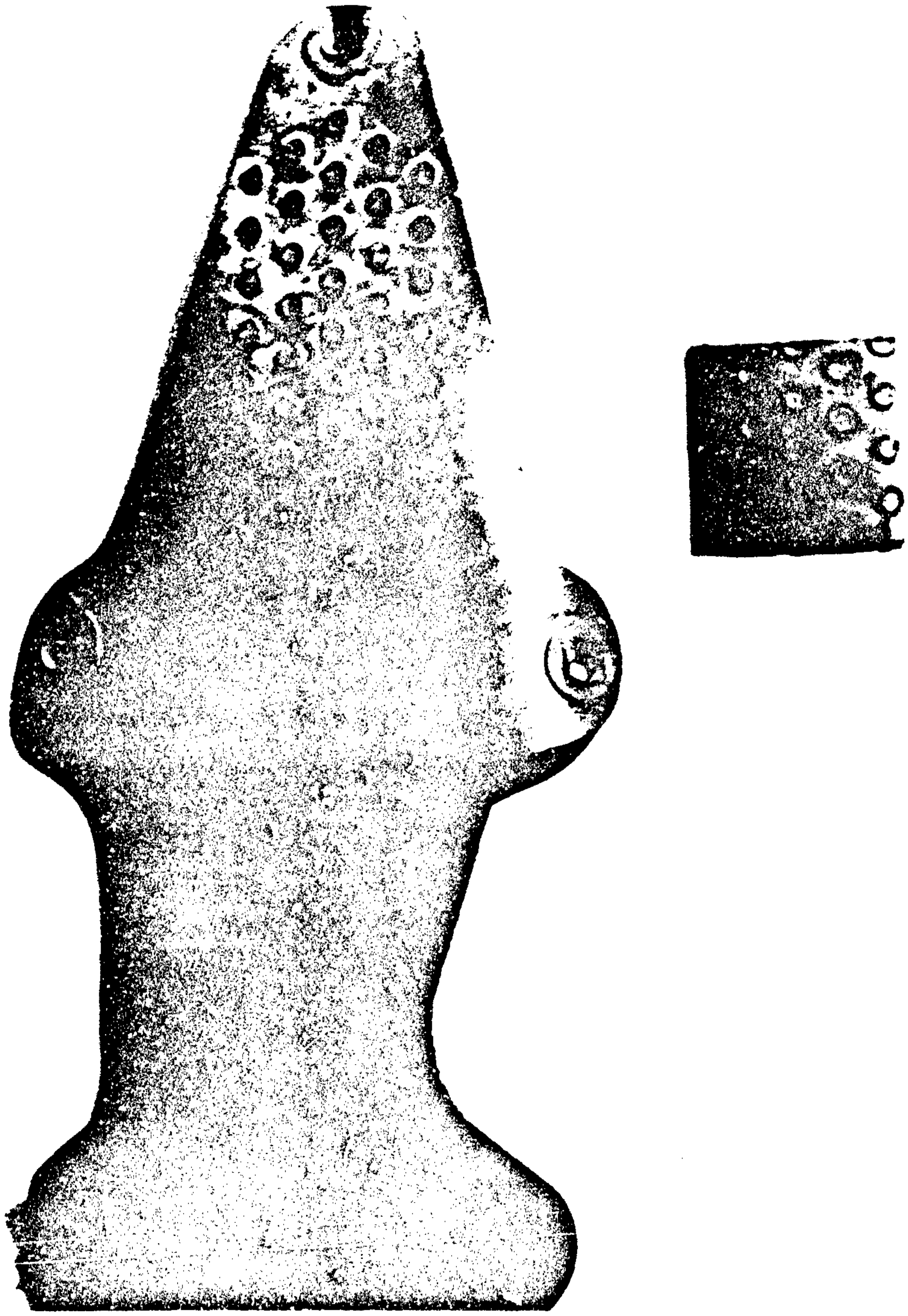

Figure A-3. UK MK III Butyl Soleing Material - Circular Plug Tread Pattern

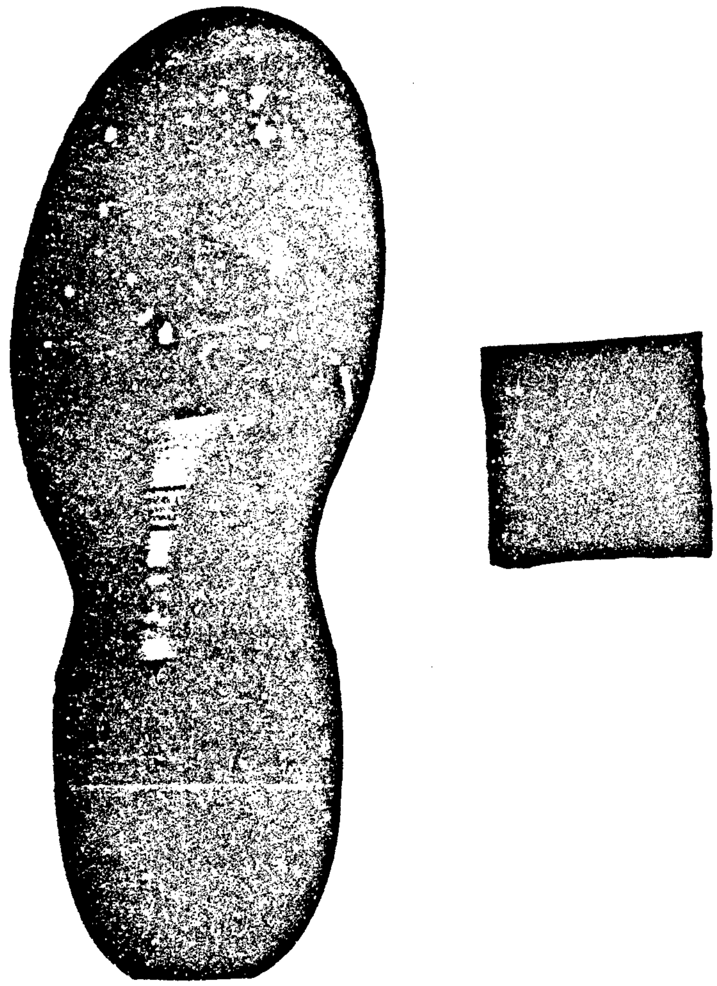

Figure A-4. GVO Vinyl Soleing Material - Conical Plug with Concave Tip Tread Pattern

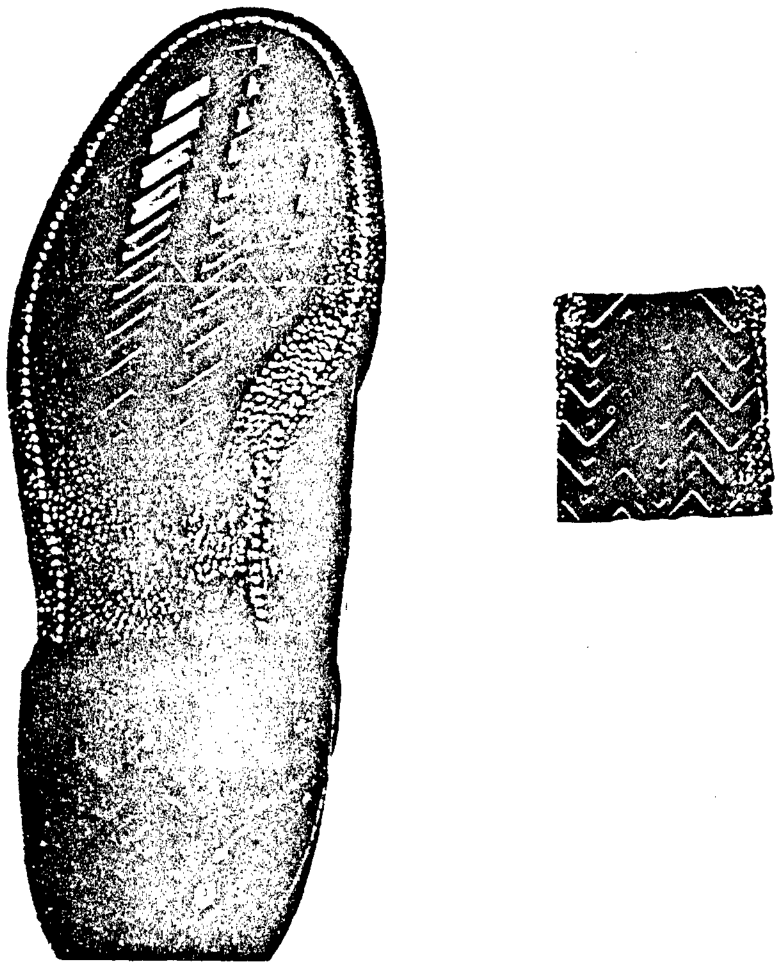

Figure A-5. Standard Nitrile Soleing Material - Chevron Tread Pattern

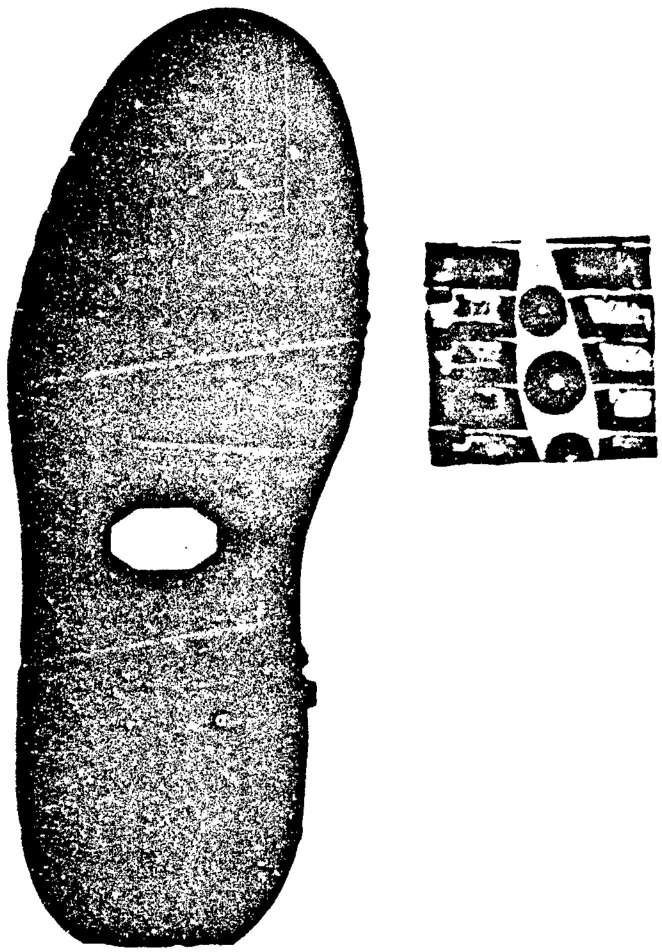

Figure A-6. Vibram 134 Nitrile Soleing Material - Cylindrical Plug and Rectangular Bar Tread Pattern

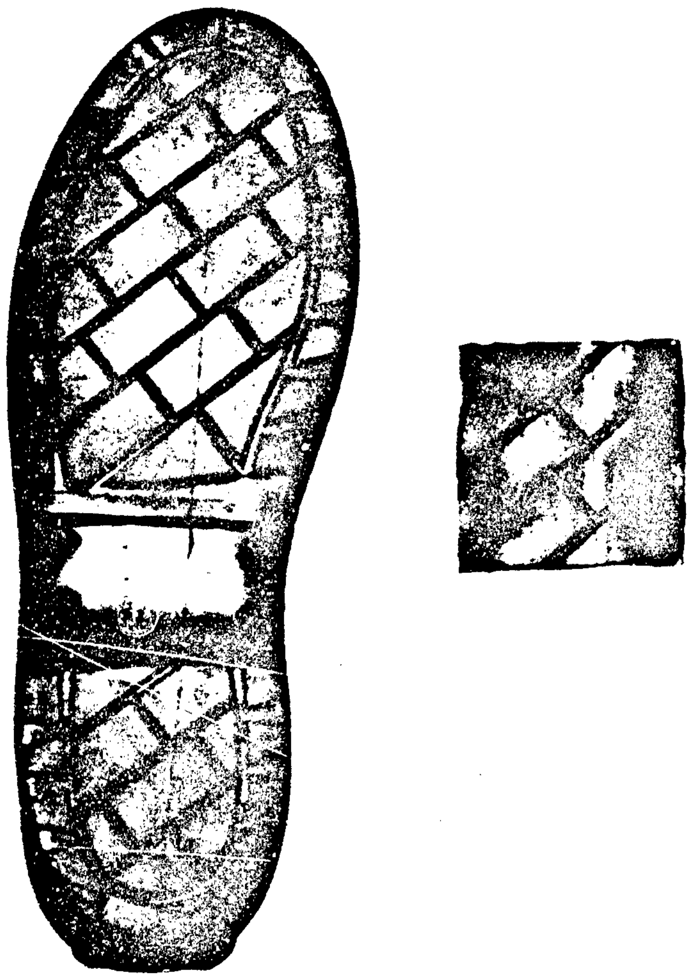

Figure A-7. Mulo Nitrile/Neoprene Soleing Material - Bias Rectangular Offset Block Tread Pattern

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